US005670999A

United States Patent [19]

Takeuchi et al.

[11] Patent Number: 5,670,999

[45] Date of Patent: Sep. 23, 1997

[54] **INK JET PRINT HEAD HAVING MEMBERS WITH DIFFERENT COEFFICIENTS OF THERMAL EXPANSION**

[75] Inventors: **Yukihisa Takeuchi**, Aichi-ken; **Nobuo Takahashi**, Owariasahi; **Shigeki Okada**, Nagoya, all of Japan

[73] Assignees: **NGK, Insulators, Ltd.**; **Seiko Epson Corporation**, both of Japan

[21] Appl. No.: **600,651**

[22] Filed: **Feb. 13, 1996**

Related U.S. Application Data

[63] Continuation of Ser. No. 110,801, Aug. 23, 1993, abandoned.

[30] **Foreign Application Priority Data**

Aug. 25, 1992 [JP] Japan 4-248773
Aug. 5, 1993 [JP] Japan 5-194730

[51] **Int. Cl.**^{6} **B41J 2/045**

[52] **U.S. Cl.** **347/70**; 347/71

[58] **Field of Search** 347/68, 71, 94, 347/44, 47, 70; 310/328, 330, 346

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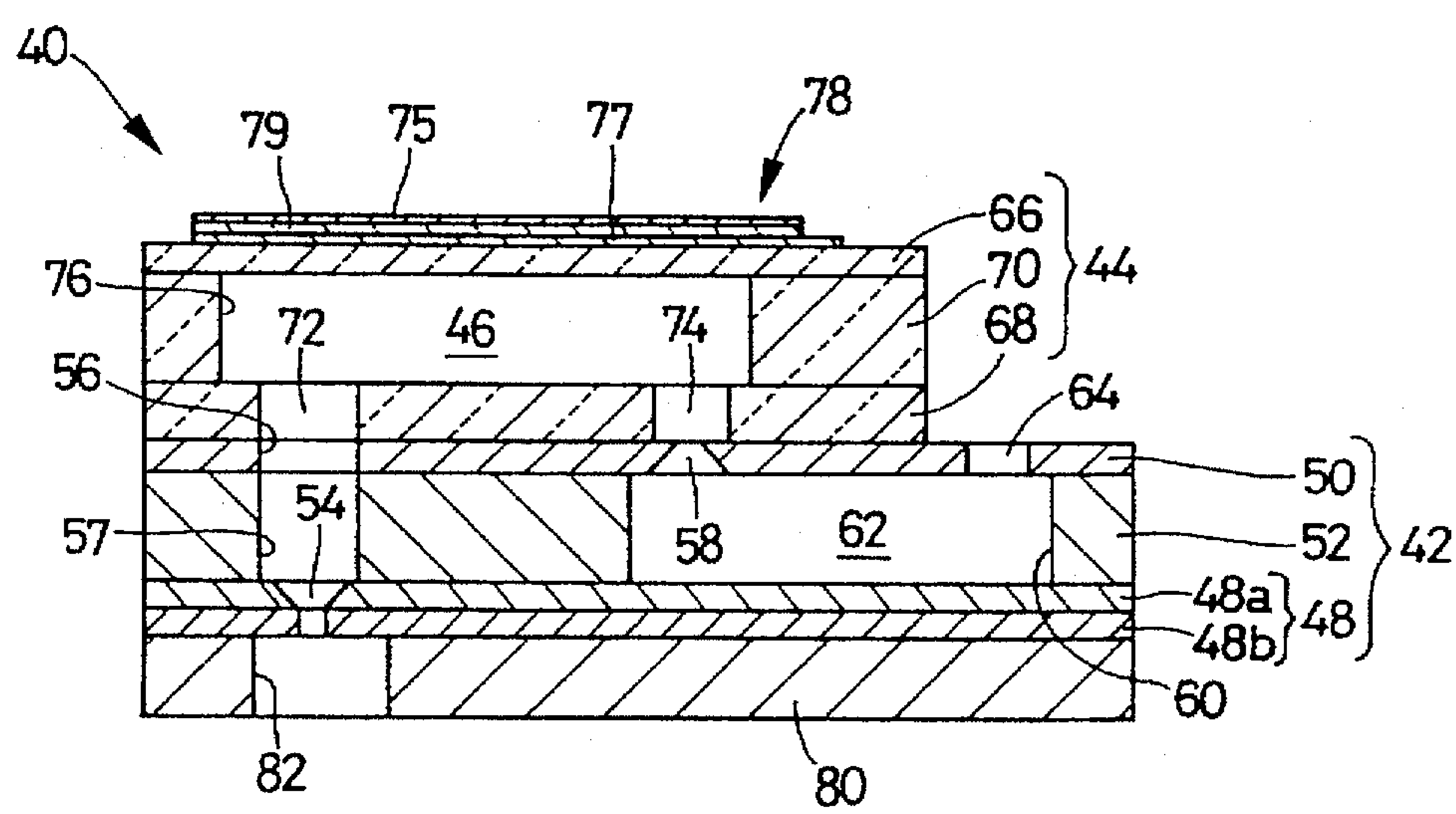
Primary Examiner—Safet Metjahic
Assistant Examiner—Michael Dalakis
Attorney, Agent, or Firm—Parkhurst, Wendel & Burr, L.L.P.

[57] **ABSTRACT**

An ink jet print head is disclosed which includes a metallic nozzle member having a plurality of nozzles through which fine particles of ink are jetted, and a ceramic ink pump member superposed on and bonded to the nozzle member. The ink pump member has a plurality of ink chambers formed behind the respective nozzles, and a plurality of piezoelectric/electrostrictive elements each disposed on a portion of the ink pump member opposite a respective ink chamber, for deforming the portion so as to change a pressure of the respective ink chamber, whereby the ink supplied to the ink chamber is jetted through the corresponding nozzle. The ink jet print head further includes a CTE (coefficient of thermal expansion) adjusting member superposed on and bonded to the nozzle member and/or the ink pump member, for reducing a stress which is applied to the ink pump member due to a difference between a coefficient of thermal expansion of the nozzle member and that of the ink pump member.

16 Claims, 8 Drawing Sheets



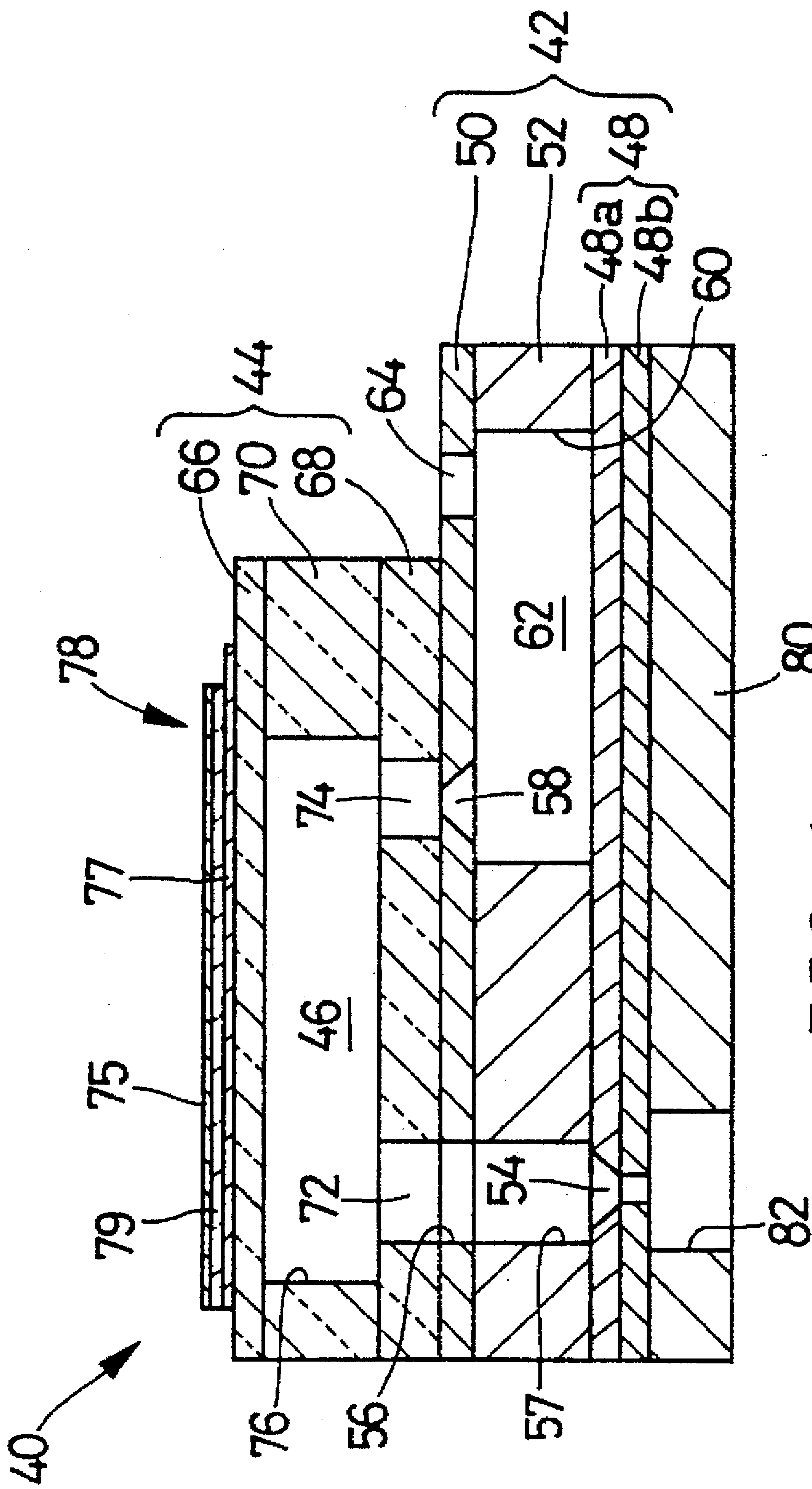

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FIG. 1

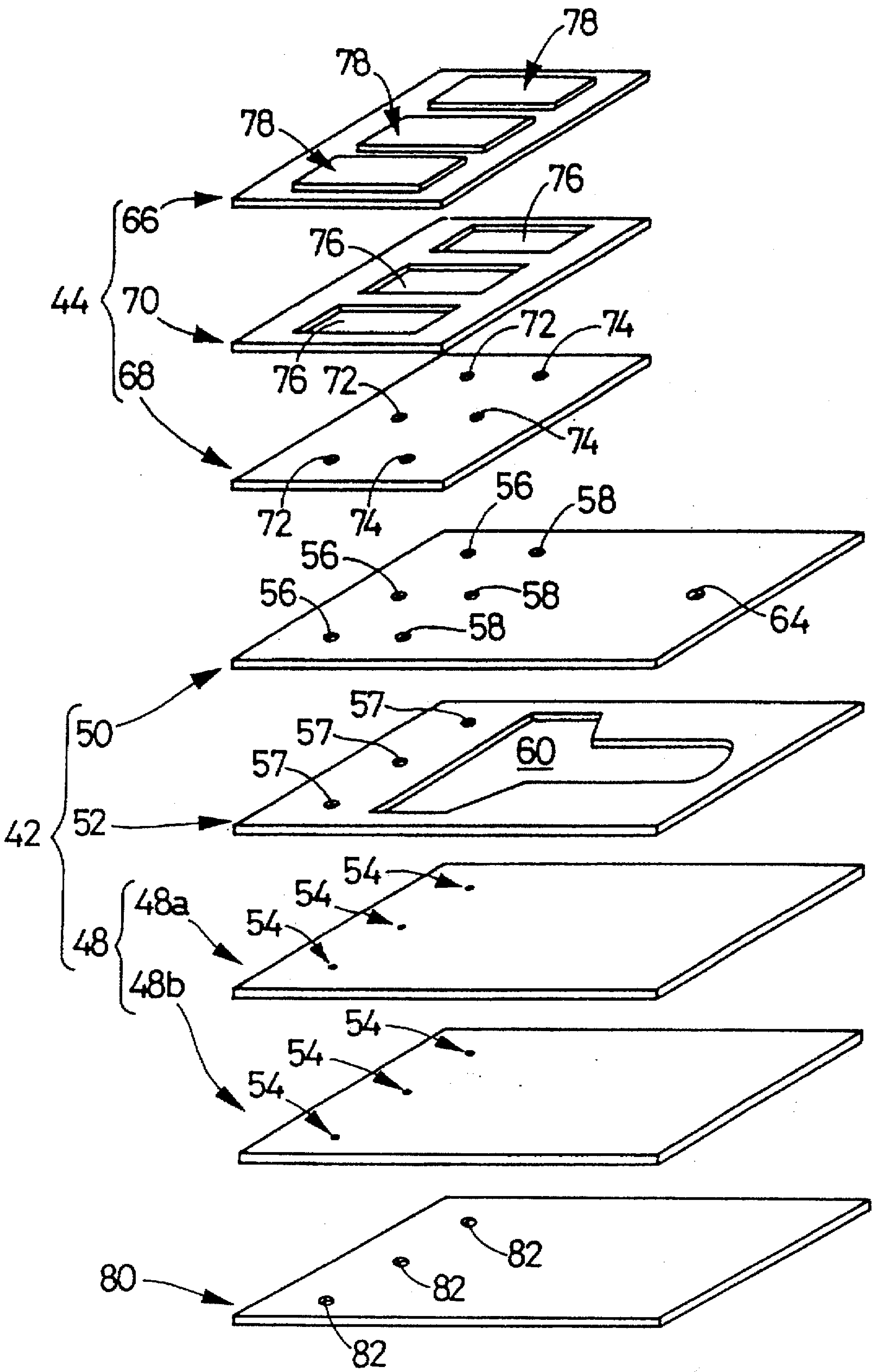
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FIG. 2

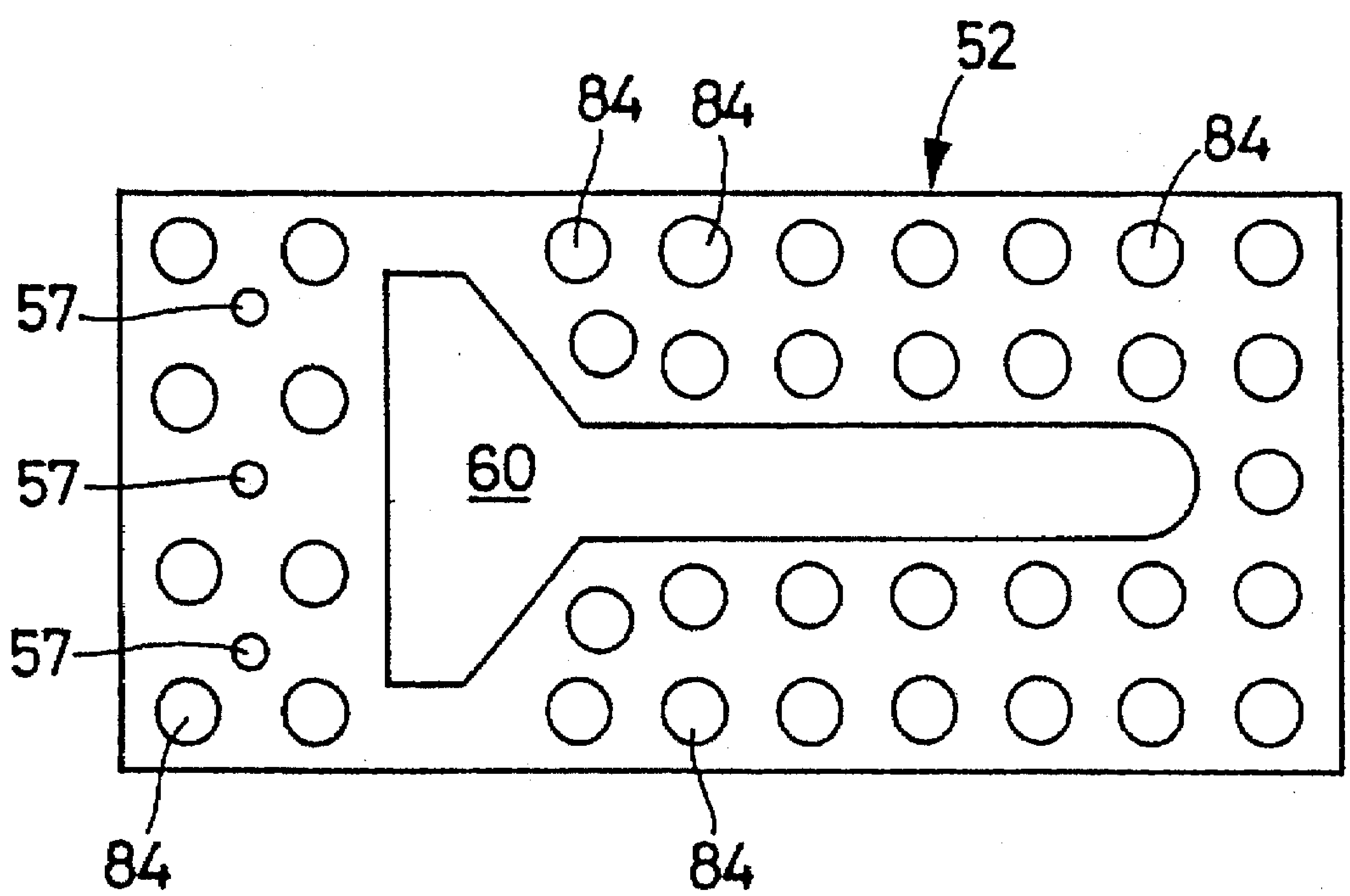

FIG. 3

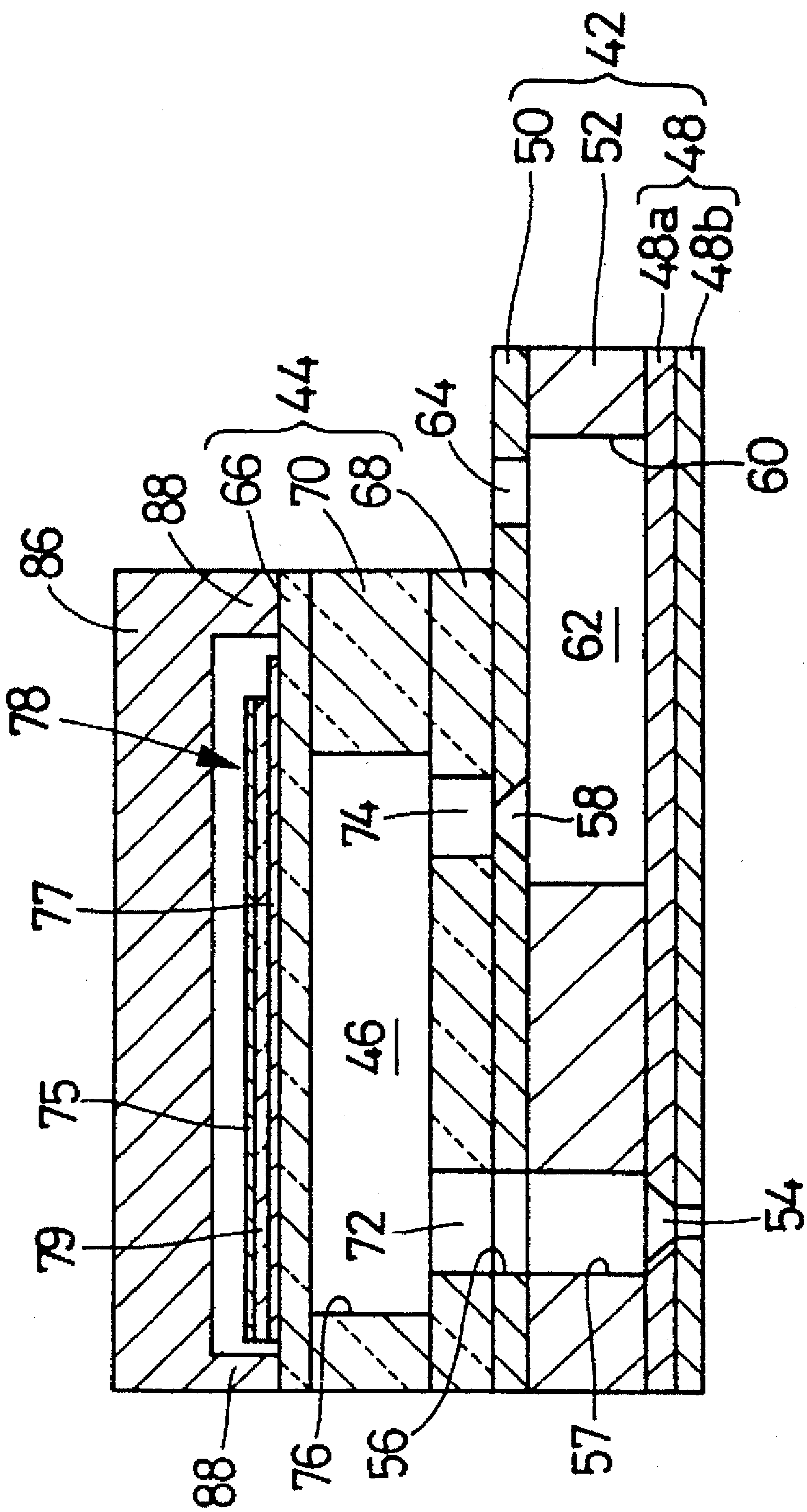
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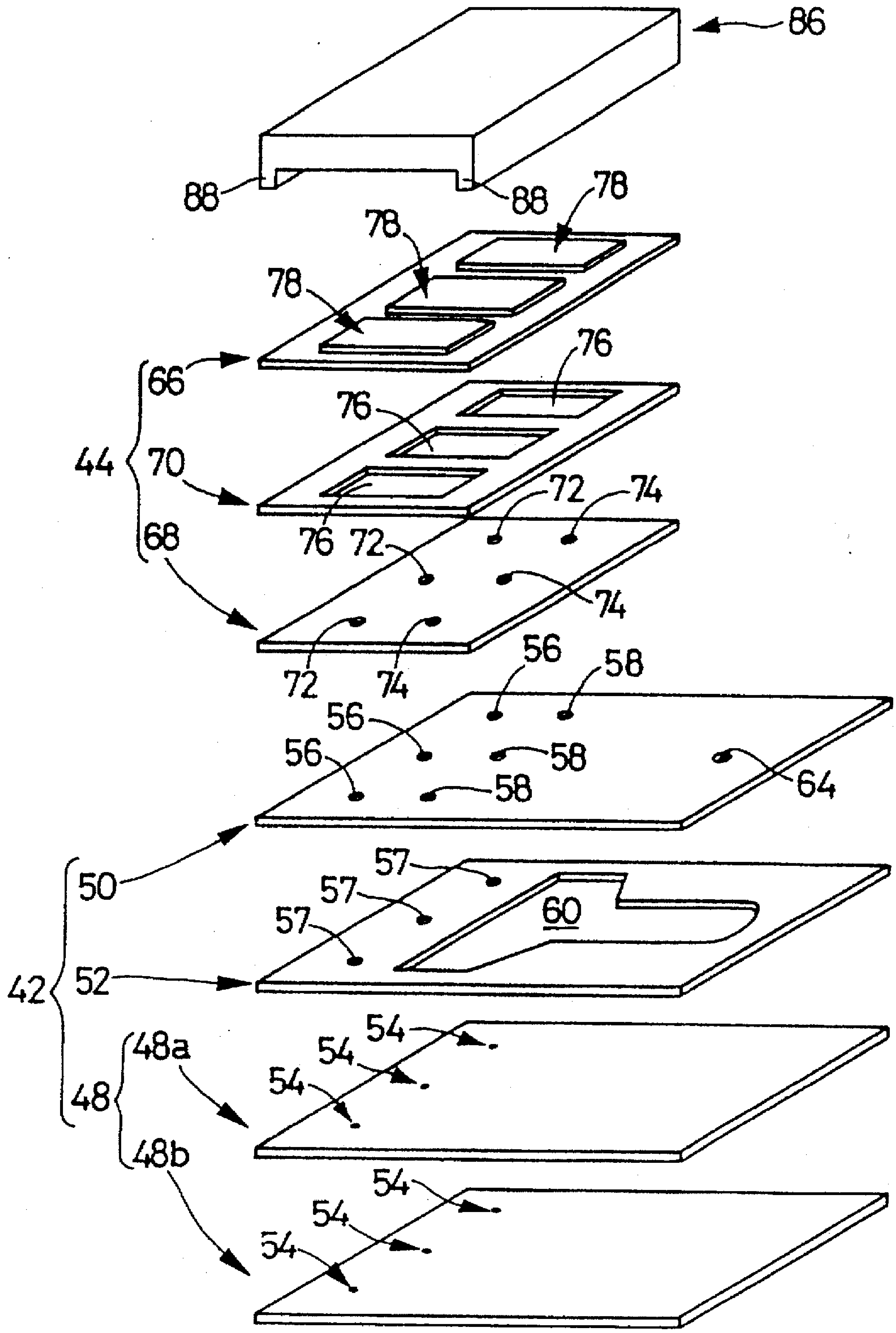
FIG. 4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48b
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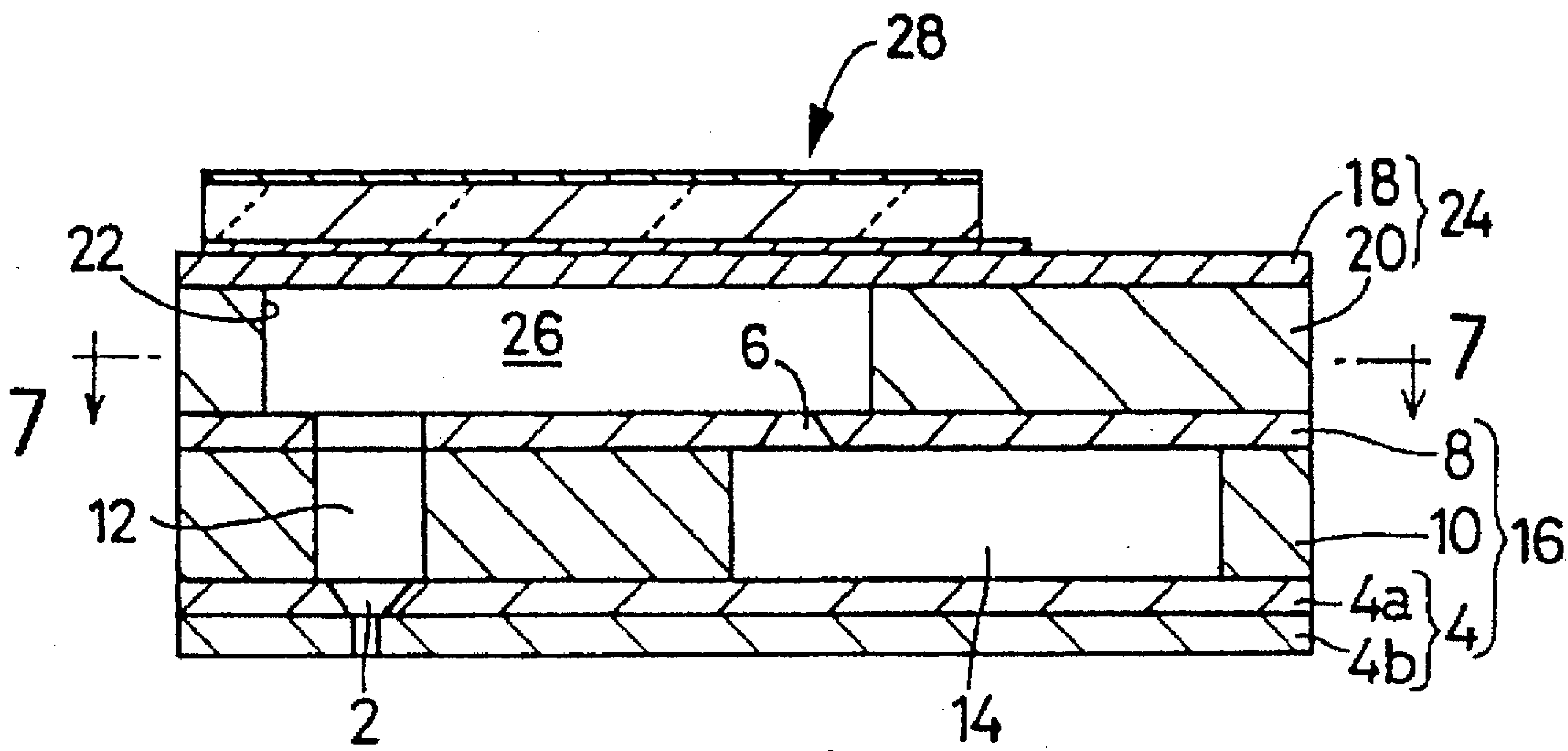
FIG. 5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4a
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4b
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FIG. 6

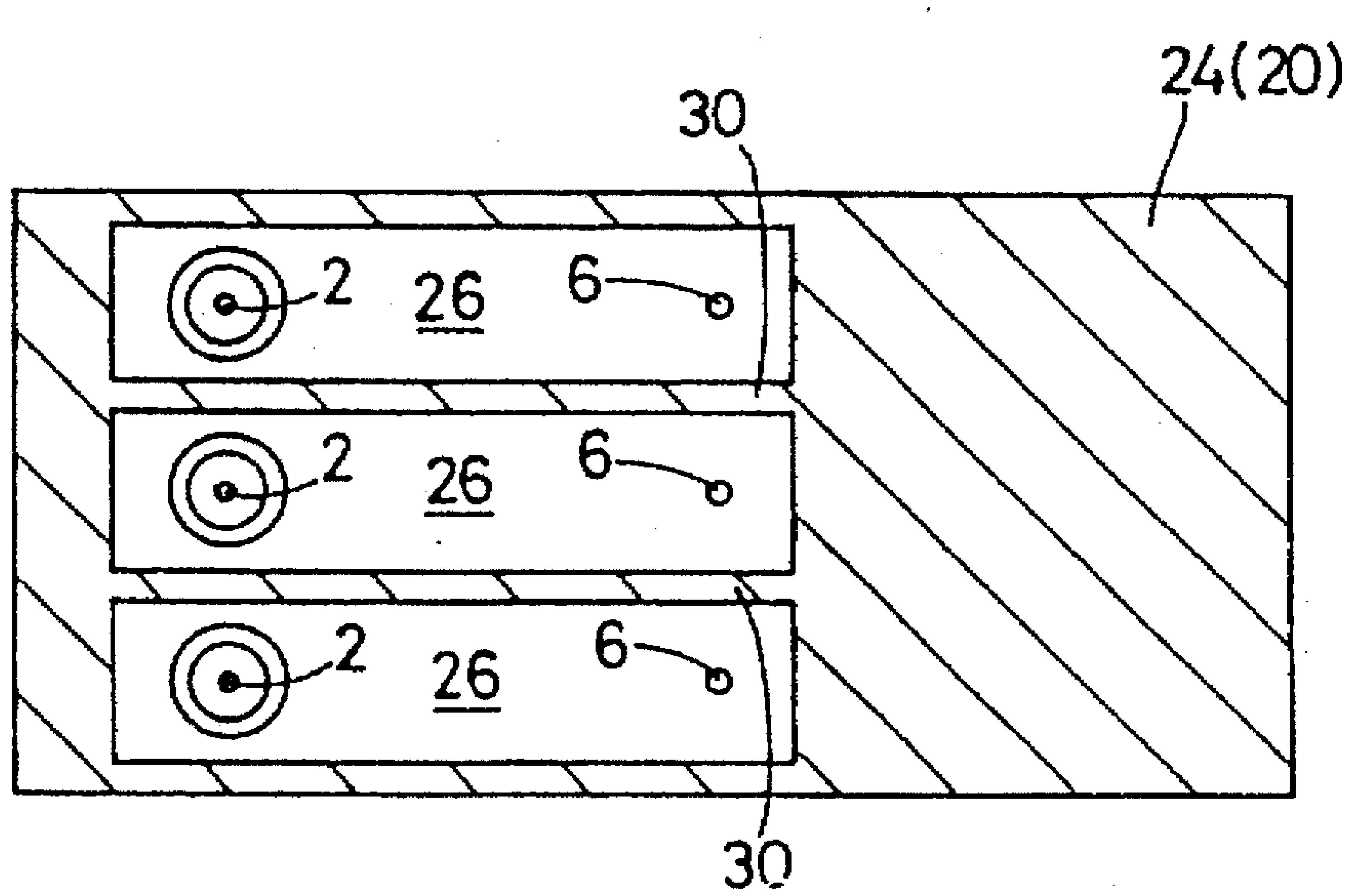
24(20)
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FIG. 7

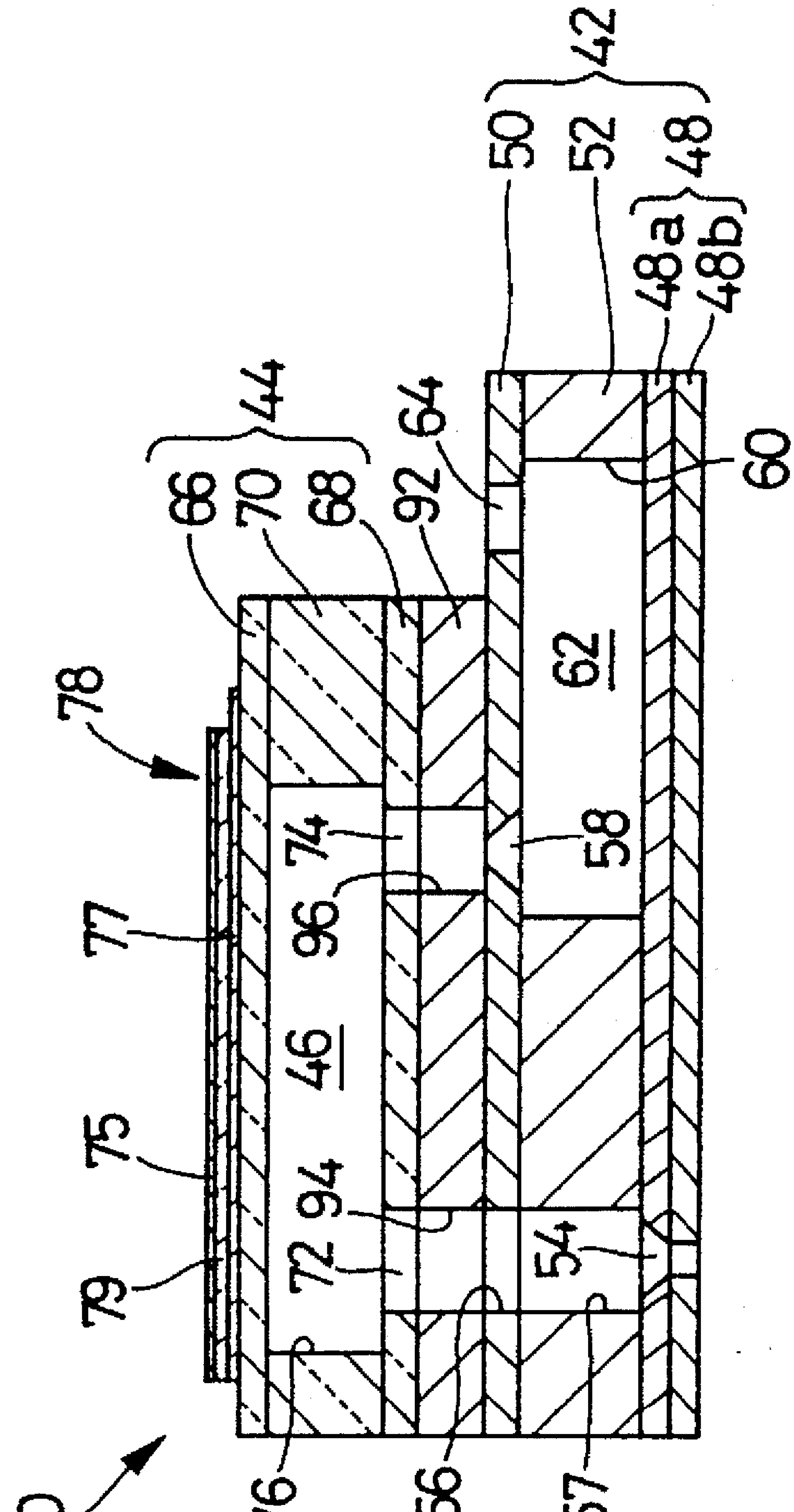
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FIG. 8

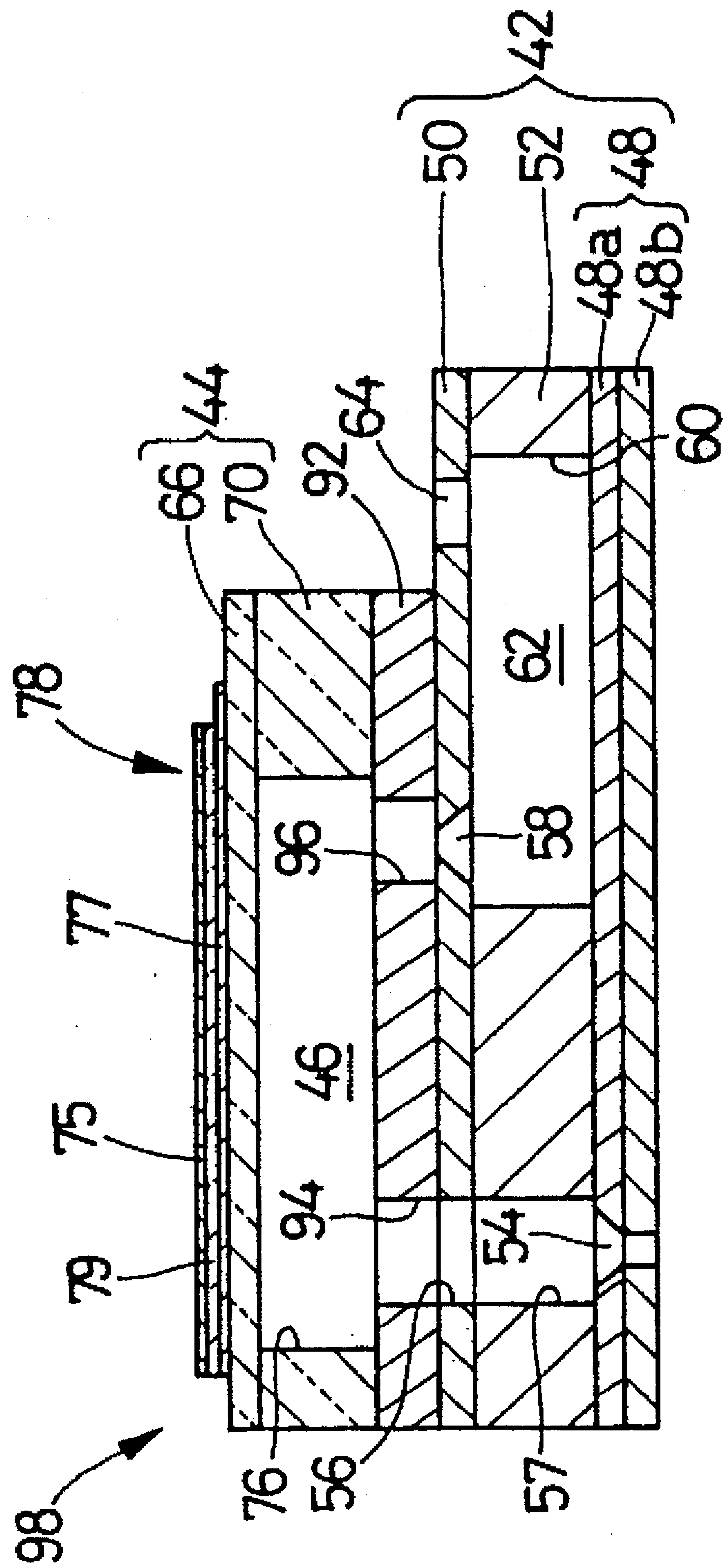
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FIG. 9

INK JET PRINT HEAD HAVING MEMBERS WITH DIFFERENT COEFFICIENTS OF THERMAL EXPANSION

This is a Continuation of application Ser. No. 08/110,801 filed Aug. 23, 1993, now abandoned.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates in general to an ink jet print head, and more particularly to such an ink jet print head that includes a nozzle member made of metal and an ink pump member (piezoelectric/electrostrictive film type actuator) made of a ceramic material, which are superposed on each other and bonded together into an integral laminar structure. The present invention is concerned with a technique for improving ink-jetting characteristics or capability of the laminar ink jet print head.

2. Discussion of the Related Art

In the recent market of printers, there is a rapidly increasing demand for an ink jet printer which operates quietly at a relatively low cost. The ink jet printer has an ink jet print head which is adapted to raise the pressure in an ink chamber filled with a mass of ink, to thereby jet or discharge fine ink particles from nozzles so as to effect a desired printing operation.

A known type of the ink jet print head uses a piezoelectric/electrostrictive element disposed on a wall of the ink chamber, as means for raising the pressure in the ink chamber. In this type of the print head, a volume of the ink chamber is changed upon energization and displacement of the piezoelectric/electrostrictive element. The ink jet print head of this type is advantageous for reduced consumption of electric power, as compared with another type of the ink print head in which the ink is heated by a heater disposed in the ink chamber, to generate minute bubbles used for jetting the fine ink particles.

Referring to FIGS. **6** and **7** showing an example of the above type of the ink jet print head utilizing the displacement of the piezoelectric/electrostrictive element, a nozzle plate **4** having a plurality of nozzles **2**, an orifice plate **8** having a plurality of orifices **6**, and a channel plate **10** are superposed on each other such that the channel plate **10** is interposed between the plates **4** and **8**. These plates **4**, **8**, **10** are bonded together into an ink nozzle member **16**, in which are formed ink discharge channels **12** for leading or guiding an ink material to the respective nozzles **2**, and an ink supply channel or channels **14** for leading the ink material to the orifices **6**. The ink jet print head further includes an ink pump member **24** which consists of two plates **18**, **24** formed in lamination on the ink nozzle member **16**. The ink pump member **24** has a plurality of voids **22** which correspond to the nozzles **2** and orifices **6**. With this ink pump member **24** superposed on and bonded to the ink nozzle member **16**, an ink chamber **26** corresponding to each of the voids **22** is formed behind the corresponding nozzle and orifice **2**, **6**. The ink pump member **24** includes a plurality of piezoelectric/electrostrictive elements **28** each fixedly formed on a relatively thin portion of the pump member **24** defining the corresponding ink chamber **26**. In this ink jet print head, the ink nozzle member **16** consisting of the nozzle plate **4**, orifice plate **8** and channel plate **10** is generally made of metal, such as stainless steel, in view of the manufacturing cost and the easiness of precision processing on the plates. As shown in FIG. **6**, the nozzle plate **4** consists of a first nozzle plate **4***a* having tapered sections of the nozzles **2**, and a second nozzle plate **4***b* having straight sections of the nozzles **2**.

The ink pump member **24** of the ink jet print head of the above type may favorably consist of a piezoelectric/electrostrictive film type actuator made principally of a ceramic material, as disclosed in JP-A-3-128681 assigned to the assignee of the present application. This piezoelectric/electrostrictive film type actuator has a ceramic substrate corresponding to the above-indicated plates **18**, **20**, and a piezoelectric/electrostrictive element formed on one of opposite major surfaces of the ceramic substrate. The piezoelectric/electrostrictive element consists of a first electrode film, a piezoelectric/electrostrictive film and a second electrode film, which are laminated in this order to form an integral laminar structure. The actuator of this type is advantageously small-sized and cheap, and assures high operating reliability. Further, this actuator is excellent in its ability to generate a large amount of displacement by application of a relatively low voltage thereto, with a sufficiently large magnitude of force generated, assuring an improved operating response. Thus, the actuator as described above can be advantageously used as the ink pump member of the ink jet print head.

The inventors of the present invention made an analysis on the ink jet print head formed by superposing the metallic nozzle member having the nozzles for jetting the ink material, on the ink pump member in the form of the piezoelectric/electrostrictive film type actuator as described above. It was revealed as a result of the analysis that the amount of displacement of the ink pump member incorporated in the print head is significantly smaller than the nominal or intended amount of displacement of the actuator itself.

In the case where the ink jet print head is formed such that the ink pump member made of ceramic and the nozzle member made of stainless steel are bonded together at a temperature of 120° C. with an adhesive, for example, the ink pump member incorporated in the print head undergoes a displacement of 0.20 μm upon application of a given voltage thereto, whereas the ink pump member as formed separately from the print head undergoes a displacement of 0.30 μm upon application of the same voltage. Thus, the amount of displacement of the ink pump member is reduced as large as more than 30% after the pump member is incorporated in the print head.

SUMMARY OF THE INVENTION

In view of the above situation, the inventors of the present invention made various analyses on the reduction of the displacement of the ink pump member, which results in deterioration of the ink jetting capability of the ink jet print head. It was revealed as a result of the analyses that the ink pump member is subject to thermal stresses generated therein, or thermal strain remaining therein, due to the heat history during the process of fabricating the print head or due to the heat application to the fabricated print head, since the nozzle member and ink pump member of the head are made of different materials, that is, metal and ceramic, which have different coefficients of thermal expansion. Consequently, the ink pump member undergoes flexural deformation or compression, due to the thermal stresses or strains, resulting in undesirably reduced amount of displacement of the ink pump member.

It is therefore an object of the present invention to provide an ink jet print head having an ink pump member which ensures a sufficiently large amount of displacement thereof upon application of a given voltage thereto, thereby assuring improved ink jetting capability of the print head.

The above object may be accomplished according to the principle of the present invention, which provides an ink jet print head comprising: a metallic nozzle member having a plurality of nozzles through which fine particles of ink are jetted; a ceramic ink pump member superposed on and bonded to one of opposite major surfaces of the nozzle member, the ink pump member having a plurality of ink chambers formed behind the respective nozzles of the nozzle member, said ink pump member including a plurality of piezoelectric/electrostrictive elements each disposed on a portion of the ink pump member defining the corresponding one of the ink chambers, for deforming the portion so as to change a pressure of the corresponding ink chamber, whereby the ink supplied to the ink chamber is jetted through the corresponding one of the nozzles; and a CTE adjusting member superposed on and bonded to at least one of the nozzle member and the ink pump member, for reducing a stress which is applied to the ink pump member due to a difference between a coefficient of thermal expansion of the nozzle member and that of the ink pump member.

According to one form of the present invention, the CTE adjusting member is superposed on and bonded to the other surface of the nozzle member remote from the ink pump member. The coefficient of thermal expansion of the CTE adjusting member is smaller than that of the nozzle member, or is even smaller than that of the ink pump member which is smaller than that of the nozzle member. With the ink pump member and CTE adjusting member having relatively small coefficients of thermal expansion being formed on the opposite surfaces of the nozzle member having a large coefficient of thermal expansion, the present print head has a laminate of three members with small-large-small coefficients of thermal expansion, whereby the thermal deformation as encountered in a bimetal can be restricted. To assure excellent printing characteristics of the ink jet print head, it is desirable that the thickness of the CTE adjusting member is as small as possible. Therefore, the CTE adjusting member is preferably formed of a material having the possibly smallest coefficient of thermal expansion and a comparatively high Young's modulus, so as to yield a desired CTE adjusting effect even with the small thickness. The nozzle member is usually formed of a material having a larger coefficient of thermal expansion than a ceramic material. However, when the nozzle member is formed of a material having a smaller coefficient of thermal expansion than a ceramic material, the print head is desirably constituted by a laminate of three members with large-small-large coefficients of thermal expansion. Namely, in this particular case, the coefficient of thermal expansion of the CTE adjusting member is preferably larger than that of the nozzle member.

According to another form of the invention, the CTE adjusting member is superposed on and bonded to one major surface of the ink pump member remote from the nozzle member. In this case, the coefficient of thermal expansion of the CTE adjusting member may be larger than that of the ink pump member, preferably, is equivalent to that of the nozzle member. Alternatively, the CTE of the CTE adjusting member may be smaller than that of the ink pump member. In either case, the CTE adjusting member serves to effectively restrict the flexural deformation of the ink pump member due to a difference in the thermal expansion and contraction characteristics between the ink pump member and the nozzle member.

According to a further form of the invention, the CTE adjusting member is interposed between and bonded to the ink pump member and the nozzle member. In this case, the CTE adjusting member is formed of a material having a smaller coefficient of thermal expansion than the nozzle member. In this arrangement, the CTE adjusting member serves to effectively restrict or reduce the thermal deformation induced by the nozzle member having the larger coefficient of thermal expansion, to thereby reduce stresses which take place in the ink pump member.

In the ink jet print head constructed according to the present invention, the CTE adjusting member is superposed on and bonded to at least one of the ink pump member and nozzle member, to cooperate with these members to constitute an integral laminar structure. Therefore, the CTE adjusting member can effectively alleviate or reduce compressive stresses or tensile stresses applied to the ink pump member due to a difference of the coefficient of thermal expansion between the metallic nozzle member and the ceramic ink pump member. In particular, the CTE adjusting member is able to effectively restrict flexural deformation of the ink pump member resulting from such stresses, so that the ink pump member can be effectively displaced by the piezoelectric/electrostrictive element, whereby the present ink jet print head exhibits significantly improved ink jetting capability.

As described above, the coefficient of thermal expansion of the CTE adjusting member used for the present invention needs to be appropriately selected depending upon the position of the CTE adjusting member in the print head. In any case, the CTE adjusting member can effectively reduce stresses applied to the ink pump member due to the heat history during the process of producing the print head. The CTE adjusting member can also effectively reduce stresses which are applied to the ink pump member due to a difference of the coefficient of thermal expansion between the nozzle member and ink pump member, when the print head is heated after it is fabricated. Consequently, the present ink jet print head is advantageously free from an adverse influence of the stresses present in the ink pump member on its ink jetting capability.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and optional objects, features and advantages of the present invention will be better understood by reading the following detailed description of presently preferred embodiments of the invention, when considered in connection with the accompanying drawings, in which:

FIG. 1 is an elevational view in vertical cross section of one embodiment of an ink jet print head of the present invention;

FIG. 2 is an exploded perspective view explaining the structure of the ink jet print head of FIG. 1;

FIG. 3 is a plan view showing an example of a channel plate of an ink nozzle member of the ink jet print head of FIG. 1;

FIG. 4 is a vertical cross sectional view corresponding to that of FIG. 1, showing an ink jet print head as another embodiment of the present invention;

FIG. 5 is an exploded perspective view corresponding to that of FIG. 2, for explaining the structure of the ink jet print head of FIG. 4;

FIG. 6 is a vertical cross sectional view showing a known ink jet print head by way of example;

FIG. 7 is a cross sectional view taken along line 7—7 of FIG. 6;

FIG. 8 is a vertical cross sectional view corresponding to that of FIG. 1, showing an ink jet print head as a further embodiment of the present invention; and

FIG. 9 is a vertical cross sectional view corresponding to that of FIG. 1, showing an ink jet print head as a still further embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1 schematically showing in cross section an ink jet print head **40** as one preferred embodiment of the present invention, and to FIG. 2 which is an exploded perspective view of the print head **40**, an ink nozzle member **42** and an ink pump member **44** are bonded together to form an integral structure of the ink jet print head **40**. In this print head **40**, an ink material is supplied to a plurality of ink chambers **46** formed in the ink pump member **44**, and is jetted or discharged from a plurality of nozzles **54** formed through the ink nozzle member **42**. The present print head further includes a CTE (coefficient of thermal expansion) adjusting plate **80** having a suitable thickness, which is bonded to one of the opposite major surfaces of the ink nozzle member **42** remote from the ink pump member **44**, in other words, to the surface of the nozzle member **42** through which the ink is jetted.

More specifically described, the ink nozzle member **42** consists of a metallic nozzle plate **48** and a metallic orifice plate **50** which are relatively thin flat plates, and a metallic channel plate **52** interposed between these plates **48, 50**. The nozzle plate **48** and the orifice plate **50** are integrally bonded to the channel plate **52** with a suitable adhesive. The nozzle plate **48** is formed by bonding a first nozzle plate **48***a* having tapered holes, and a second nozzle plate **48***b* having straight holes, such that the nozzle plate **48** have a plurality of nozzles **54** (three in this embodiment) for permitting jets of fine ink particles, each nozzle **54** consisting of one tapered hole and one straight hole of the respective plates **48***a*, **48***b*. The orifice plate **50** and the channel plate **52** have respective through-holes **56, 57** formed through the thickness thereof. These through-holes **56, 57** are aligned with the respective nozzles **54** as viewed in the direction of the thickness of the plates **48, 50, 52**, and have a diameter which is larger by a given value than that of the nozzles **54**.

The orifice plate **50** further has a plurality of orifices **58** (three in this embodiment) formed therethrough, for permitting flow of the ink into the respective ink chambers **46**. The channel plate **52** is formed with a window **60** which is closed at its opposite openings by the nozzle plate **48** and orifice plate **50**, respectively, whereby an ink supply channel **62** communicating with the orifices **58** is defined by the channel plate **52**, nozzle plate **48** and orifice plate **50**. The orifice plate **50** further has a supply port **64** through which the ink is fed from an ink reservoir into the ink supply channel **62**.

The plates **48, 50, 52** of the ink nozzle member **42** are preferably formed of a metallic material, such as nickel or stainless steel. With the plates **48, 50** made of metal, the nozzles **54** and orifices **58** can be formed through the respective plates **48, 50** with high dimensional accuracy. Each of the orifices **58** is desirably formed in tapered shape such that the diameter of the orifice **58** is reduced in the direction of flow of the ink (i.e., the direction from the ink supply channel **62** toward the ink chambers **46**), as shown in FIG. **1** by way of example, so as to function as a check valve for reducing the ink from flowing in the reverse direction. In the instant embodiment, the plates **48, 50** and **52** are made of stainless steel (SUS**304**), and fine holes like the nozzles and orifices **54, 58** are formed by punching, while the contours of the plates **48, 50, 52** are established by a combination of photolithography and etching. Then, these plates **48, 50** and **52** are bonded together by an epoxy-type adhesive, for example, to thereby form the integral ink nozzle member **42**.

Other than the epoxy-type adhesive as indicated above, the adhesive used herein may consist of a hot-melt type adhesive film containing nylon or polyolefin, provided the adhesive is sufficiently resistant to heat generated in the subsequent heat treatment step needed for bonding the plates **48, 50, 52** together.

The ink pump member **44** includes a closure plate **66** and a connecting plate **68** which are relatively thin flat plates, and a spacer plate **70** interposed between the plates **66, 68**. These plates **66, 68, 70** are superposed on each other and formed integrally into the ink pump member **44**.

The connecting plate **68** has first communication holes **72** and second communication holes **74** formed therethrough, which are respectively aligned with the through-holes **56** and orifices **58** formed in the orifice plate **50**, as viewed in the direction of the thickness of the plates **68, 50**. The diameter of the first communication holes **72** is substantially equal to or slightly larger than that of the through-holes **56**, while the diameter of the second communication holes **74** is larger by a given value than that of the orifices **58**.

The spacer plate **70** has a plurality of rectangular windows **76** formed therethrough. The spacer plate **70** is superposed on the connecting plate **68** such that each of the windows **76** communicates with the corresponding first and second communication holes **72, 74** formed in the connecting plate **68**.

On one major surface of the spacer plate **70** remote from the connecting plate **68**, there is superposed the above-indicated closure plate **66** for closing the openings of the windows **76**. Thus, the above-indicated ink chambers **46** are formed in the ink pump member **44**, such that the chambers **46** communicate with an exterior space through the first and second communication holes **72, 74**.

The ink pump member **44** is formed as an integrally formed fired ceramic structure. More specifically, green sheets as precursors for the closure plate **66**, connecting plate **68** and spacer plate **70** are initially formed, laminated on each other, and then fired into an integral ceramic body as the ink pump member **44**. While the ceramic material used for forming the ink pump member **44** is not limited to any particular kinds, alumina, zirconia and the like may be favorably employed in view of its formability and other properties. In this embodiment, the ink pump member **44** is formed of zirconia which contains 3 mol % of Y_2O_3. The closure plate **66** has a thickness of 10 μm, and the connecting plate **68** has a thickness of 180 μm, while the spacer plate **70** has a thickness of 180 μm.

The ink pump member **44** further has piezoelectric/electrostrictive elements **78** formed on the outer surface of the closure plate **66**, such that the elements **78** correspond to the respective ink chambers **46** formed in the member **44**. Each of the piezoelectric/electrostrictive elements **78** has a piezoelectric/electrostrictive unit consisting of a lower electrode **75**, a piezoelectric/electrostrictive layer **79** and an upper electrode **77**, which are formed in lamination on the closure plate **66**, by a suitable film-forming method. As the piezoelectric/electrostrictive element **78** of the instant embodiment, it is particularly preferable to employ a piezoelectric/electrostrictive element as proposed in co-pending U.S. patent application No. 07/912,920 assigned to the same assignee as the present application.

More specifically, films of the lower and upper electrodes **75, 77** and piezoelectric/electrostrictive layers **79** are formed on the outer surface of the closure plate **66**, by any one of various known methods which include thick-film forming processes, such as screen printing, spraying, dipping and coating, and thin-film forming processes, such as ion-beam method, sputtering, vacuum vapor deposition, ion plating, CVD and plating. The formation of these layers **75**, **77**, **79** may be effected either before or after sintering of the closure plate **66** (the ink pump member **44**). Then, the electrode films **75**, **77** and piezoelectric/electrostrictive layer **79** thus formed on the closure plate **66** may be heat-treated as needed, either in different steps following formation of the respective films and layer **75**, **77**, **79**, or in one step following formation of all the films and layer **75**, **77**, **79**.

The electrode films **75**, **77** of each piezoelectric/electrostrictive unit may be formed of any electrically conductive material which can withstand a high-temperature oxidizing atmosphere generated upon the heat-treatment or firing as described above. For instance, the electrode films **75**, **77** may be formed of a single metal, an alloy of metals, a mixture of a metal or alloy and an insulating ceramic or glass, or an electrically conductive ceramic. Preferably, the electrode material contains as a major component a noble metal having a high melting point, such as platinum, palladium or rhodium, or an alloy such as silver-palladium alloy, silver-platinum alloy or platinum-palladium alloy.

The piezoelectric/electrostrictive layer **79** of each piezoelectric/electrostrictive unit may be formed of any piezoelectric or electrostrictive material which produces a relatively large amount of strain or displacement due to the converse or reverse piezoelectric effect or the electrostrictive effect. The piezoelectric/electrostrictive material may be either a crystalline material or an amorphous material, and may be a semi-conductor material or a dielectric or ferroelectric ceramic material. Further, the piezoelectric/electrostrictive material may either require a treatment for initial polarization or poling, or may not require such a polarization treatment.

The piezoelectric/electrostrictive material used for the piezoelectric/electrostrictive layer **79** preferably contains as a major component lead zirconate titanate (PZT), lead magnesium niobate (PMN), lead nickel niobate (PNN), lead manganese niobate, lead antimony stannate, lead zinc niobate, lead titanate, or a mixture thereof. The piezoelectric/electrostrictive material having the above major component may further contain as an additive an oxide or other compound of lanthanum, strontium, barium, niobium, zinc, cerium, cadmium, chromium, cobalt, antimony, iron, yttrium, tantalum, tungsten, nickel, and/or manganese, so as to provide a material containing PLZT, for example.

The piezoelectric/electrostrictive unit consisting of the electrodes **75**, **77** and piezoelectric/electrostrictive layer **79** generally has a thickness of not larger than 100 μm. The thickness of each electrode **75**, **77** is generally 20 μm or smaller, preferably 5 μm or smaller. To assure a relatively large amount of displacement with a relatively low voltage, the thickness of the piezoelectric/electrostrictive layer **79** is preferably 50 μm or smaller, more preferably, within a range of 3 μm to 40 μm. In this embodiment, the piezoelectric/electrostrictive layer **79** has a thickness of 30 μm, and is formed of a material which contains lead magnesium niobate, lead zirconate and lead titanate as major components. The upper electrode **75** consists of a copper layer and a chromium layer and formed by sputtering, and the lower electrode **77** is formed by printing and firing a platinum paste.

Further, the above-indicated CTE adjusting plate **80** is integrally bonded to the outer surface of the nozzle plate **48** of the ink nozzle member **42**. The CTE adjusting plate **80** has a plurality of through-holes **82** formed therethrough, which are aligned with the nozzles **54** formed in the nozzle plate **48**, as viewed in the direction of the thickness of the plates **48**, **80**. The through-holes **82** have a larger diameter than that of the nozzles **54**, so as not to interrupt the ink jetting from the nozzles **54**. This CTE adjusting plate **80** serves to reduce the stress that is applied to the ink pump member **44** and then to the piezoelectric/electrostrictive element **78** due to a difference in the coefficient of thermal expansion between the ink nozzle member **42** and the ink pump member **44**. The CTE adjusting plate **80** is preferably formed of a material having a smaller coefficient of thermal expansion than the metallic ink nozzle member **42**, and more preferably formed of a material having a smaller coefficient of thermal expansion than the ink pump member **44** whose CTE is smaller than that of the ink nozzle member **42**. Generally, the CTE adjusting plate is formed of a ceramic material such as alumina.

The material and dimensions (e.g., thickness) of the CTE adjusting plate **80** may be optimally selected or determined depending upon those of the ink nozzle member **42** and ink pump member **44**. More specifically, the material and dimensions of the CTE adjusting plate **80** are generally selected in view of the apparent coefficient of thermal expansion (CTE) of the ink pump member **44**, and the apparent CTE and the rigidity of the ink nozzle member **42**, in an attempt to restrain the thermal expansion and contraction of the ink nozzle member **42** to be commensurate with the CTE of the ink pump member **44**. The rigidity of the ink nozzle member **42** is determined by the Young's modulus and the shape of the nozzle member **42**. Then, the material and dimensions of the plate **80** are more specifically determined by experiments. In particular, the CTE adjusting plate **80** is preferably made of a material which has a relatively high Young's modulus, and exhibits the apparent coefficient of thermal expansion that is substantially equal to the CTE of the ink pump member **44**, when measured after the adjusting plate **80** is bonded to the nozzle member **42**. The higher the Young's modulus of the CTE adjusting plate **80** is, the smaller thickness of the plate **80** is needed for achieving sufficiently high rigidity. The CTE adjusting plate **80** desirably has a small thickness since a sufficiently large distance can be maintained between the ink jet print head and a recording medium. In this context, the CTE adjusting plate **80** desirably has a thickness of about 0.1 mm or smaller. In the instant embodiment, the CTE adjusting plate **80** consists of a 96% alumina plate having a thickness of 280 μm, which is formed by a tape forming method, punching and firing.

Alumina which provides the CTE adjusting plate **80** of the ink jet print head of the instant embodiment has a coefficient of thermal expansion of about 8×10^{-6}/°C. This CTE of the alumina is lower than that of zirconia (10×10^{-6}/°C.) which mainly forms the ink pump member **44** of this embodiment, and is also lower than the CTE of SUS**304** (16×10^{-6}/°C.) which forms the ink nozzle member **42**. Accordingly, the apparent coefficient of thermal expansion of the bonded assembly of the ink nozzle member **42** and the CTE adjusting plate **80** can be made substantially equal to the CTE of the ink pump member **44**, by properly controlling the thickness of the CTE adjusting plate **80**. In the instant embodiment, the thickness of the CTE adjusting plate **80** is controlled to be 280 μm as a result of simple calculation. It is more desirable to determine the thickness of the CTE adjusting plate **80** based on data obtained by experiments, or by computer simulation.

The adhesive used for bonding the ink nozzle member **42** and ink pump member **44** may be selected from various known adhesives, such as those of vinyl-type, acrylic-type and epoxy-type, or those containing polyamide, phenol, resorcinol, urea, melamine, polyester, furan, polyurethane, silicone, rubber, polyimide and polyolefin, provided the selected adhesive is resistant to the ink material.

It is desirable in terms of production efficiency that the adhesive is in the form of a highly viscous paste which can be applied by coating using a dispenser, or by screen-printing, or is in the form of a sheet which permits punching therethrough. The adhesive in the form of a highly viscous paste may be obtained by mixing an adhesive material with a filler to thereby increase the viscosity of the resulting adhesive.

A sample of the ink jet print head **40** constructed as shown in FIGS. **1** and **2** was produced in the following manner. Initially, the ink pump member **44**, ink nozzle member **42** and CTE adjusting plate **80** were prepared according to the instant embodiment. Then, these members and plate **44**, **42**, **80** were stacked at a pressure of 2 kg/cm^2, and bonded together at 120° C. for an hour, by using an epoxy type adhesive. As a comparative sample, there was produced an ink jet print head which is not provided with the CTE adjusting plate **80**. The thus obtained two specimens of ink jet print heads were evaluated by measuring the amount of displacement of the piezoelectric/electrostrictive element **78** of each head when a given voltage is applied to the element **78**. The measurement revealed that the ink jet print head **40** having the CTE adjusting plate **80** exhibited a displacement of 0.28 μm whereas the print head as the comparative sample having no CTE adjusting plate exhibited a displacement of as small as 0.21 μm.

In the ink jet print head **40** constructed according to the present invention, the CTE adjusting plate **80** serves to effectively reduce or eliminate stresses due to the difference in the coefficient of thermal expansion between the ink nozzle member **42** and the ink pump member **44**, which stresses are tensile stresses caused by flexural deformation of the ink pump member **44** in the above-described embodiment. Accordingly, the ink pump member **44** and the piezoelectric/electrostrictive element **78** undergo desired amounts of displacement thereof without suffering from the stress applied to the pump member **44**. Consequently, the present print head **40** assures significantly improved operating characteristics of the ink pump member **44**, and accordingly improved ink jetting capability.

In the ink jet print head **40** as described above, the material for the piezoelectric/electrostrictive element **78** disposed on the ink pump member **44** is different from the material for the closure plate **66**, connecting plate **68** and spacer plate **70** of the ink pump member **44**. In the process of producing the print head **40**, therefore, thermal stresses remain in the piezoelectric/electrostrictive element **78**, in particular, in the piezoelectric/electrostrictive layer **79**, due to the difference of the CTE between these different materials for the element **78** and pump member **44**. Such thermal stresses can also be effectively reduced by the CTE adjusting plate **80**, resulting in improved durability of the piezoelectric/electrostrictive layer **79**, and improved displacement characteristics of the piezoelectric/electrostrictive element **78** and the ink pump member **44**.

As described above, it is desirable to reduce the thickness of the CTE adjusting plate **80** to a minimum. FIG. **3** shows another embodiment of the invention which includes a means for reducing the thickness of the CTE adjusting plate **80**. In this figure, there is illustrated another form of the channel plate **52** of the ink nozzle member **42** of the ink print head as shown in FIGS. **1** and **2**. This channel plate **52** is formed of 42% Ne-Fe alloy having a coefficient of thermal expansion of 7×10^{-6}/°C., which is smaller than that of SUS**304**. The channel plate **52** has a multiplicity of holes **84** formed therethrough over the entire area of its surface except the window **60** and through-holes **57**, as shown in FIG. **3**, whereby the plate **52** has a mesh-like configuration and exhibits relatively low rigidity.

On the other hand, the CTE adjusting plate **80** of the instant embodiment is formed of a material having 96% of alumina, and has a thickness of 100 μm. When a given voltage is applied to the piezoelectric/electrostrictive element **78** of this embodiment, the element **78** undergoes a displacement of 0.28 μm, which is equivalent to that obtained in the previous embodiment, even though the thickness (100 μm) of the CTE adjusting plate **80** is smaller than that of the plate **80** of the previous embodiment.

In the manner as described above, the thickness of the CTE adjusting plate **80** can be further reduced by optimally designing the shape of the channel plate **52**. In the extreme case, the thickness of the CTE adjusting plate **80** can be reduced to zero, by suitably selecting the material of the channel plate **52** and/or optimally designing other portions of the print head, so as to appropriately control the thermal stress in the print head. In this case, the channel plate **52** per se can be considered as the CTE adjusting plate.

In the illustrated embodiments, the CTE adjusting plate **80** is superposed on the surface of the ink nozzle member **42** which is opposite to the surface thereof to which the ink pump member **44** is bonded. However, the location of the CTE adjusting member (**80**) in the ink jet print head of the present invention may be suitably selected as needed, provided the adjusting member (**80**) is able to reduce the stress applied to the ink pump member **44** due to the difference of the coefficient of thermal expansion between the ink nozzle member **42** and the ink pump member **44**. In another embodiment of the invention as shown in FIGS. **4** and **5**, a plate-like CTE adjusting member **86** is superposed on and integrally bonded to the the surface of the ink pump member **44** which is opposite to the surface thereof to which the ink nozzle member **42** is bonded.

The ink nozzle member **42** and the ink pump member **44** used in the first embodiment of FIGS. **1** and **2** are used in the instant embodiment of FIGS. **4** and **5**. Namely, the instant embodiment is different from the first embodiment only in respect of the CTE adjusting member. As shown in FIGS. **4** and **5**, the CTE adjusting member **86** of this embodiment is provided on the side of the ink pump member **44** on which the piezoelectric/electrostrictive element **78** is provided, such that the adjusting member **86** passes over the element **78**. More specifically, the CTE adjusting plate **86** takes the form of a lid having opposite leg portions **88**, **88**, which are bonded to the upper surface of the closure plate **66** of the ink pump member **44**. Thus, the CTE adjusting plate **86** is formed as an integral part of the ink jet print head.

The CTE adjusting member **86** thus positioned in the print head may be formed of a material, such as alumina, which has a relatively small coefficient of thermal expansion (contraction), as in the first embodiment. When the CTE of the material of the CTE adjusting member **86** is smaller than that of the ink pump member **44**, the CTE adjusting member **86** serves to effectively reduce or restrict the stress on the pump member **44**, in other words, its flexural deformation, caused by the thermal expansion and contraction of the ink nozzle member **42** having a relatively large coefficient of thermal expansion. Alternatively, the CTE adjusting member **86** may be formed of a material having a larger coefficient of thermal expansion than the ink pump member **44**. Particularly, the coefficient of thermal expansion of the CTE adjusting member **86** may be substantially equal to that of the ink nozzle member **42**. In this case, too, the flexural deformation of the ink pump member **44** can be effectively reduced or restricted, assuring improved ink jetting capability of the ink jet print head.

To effectively alleviate the flexural deformation of the ink nozzle member **42** and ink pump member **44**, the CTE adjusting member **86** used in the instant embodiment of FIGS. **4** and **5** is formed of stainless steel (SUS304) as used for the ink nozzle member **42**, and has a thickness of 300 μm. The ink pump member **44** of the thus obtained ink jet print head undergoes a displacement of 0.29 μm when a given voltage is applied to the piezoelectric/electrostrictive element **78**, whereas the ink pump member **44** of the ink jet print head which does not include the above-described CTE adjusting member **86** undergoes a displacement of as small as 0.21 μm. It will be readily understood that the provision of the CTE adjusting member **86** leads to significantly improved ink jetting capability of the ink jet print head.

Referring next to FIG. **8** showing an ink jet print head **90** as a further embodiment of the present invention, the print head includes the ink nozzle member **42** and the ink pump member **44** as used in the illustrated embodiments, and a CTE adjusting plate **92** interposed between the ink pump member **44** and ink nozzle member **42**. More specifically, the CTE adjusting plate **92** is bonded at its opposite major surfaces to the connecting plate **68** of the ink pump member **44** and the orifice plate **50** of the ink nozzle member **42**, such that the adjusting plate **92** is sandwiched between these plates **68**, **50**. The CTE adjusting plate **92** has a first set of through-holes **94** and a second set of through-holes **96** formed therethrough, which are respectively aligned with the first communication holes **72** and the second communication holes **74** formed through the connecting plate **68** of the ink pump member **44**, as viewed in the direction of the thickness of the plates **68**, **92**. These through-holes **94** and **96** have substantially the same diameter of the communication holes **72** and **74**, respectively. The ink chambers **46** of the ink pump member **44** are held in communication with the nozzles **54** and the orifices **58** of the ink nozzle member **42**, via the respective sets of the through-holes **94**, **96**.

The CTE adjusting plate **92** used in this embodiment is formed of a material having a smaller coefficient of thermal expansion than the ink nozzle member **42**. Preferably, the coefficient of thermal expansion of the CTE adjusting plate **92** is equivalent to that of the ink pump member **44**. The CTE adjusting plate **92** thus provided in the print head serves to effectively reduce or eliminate tensile stresses based on the flexural deformation of the ink pump member **44** caused by the thermal expansion and contraction of the ink nozzle member **42** having a relatively large coefficient of thermal expansion. The thus constructed ink jet print head **90** is advantageous over the print head as shown in FIGS. **1** and **2**, in that the thickness of the CTE adjusting plate **92** can be selected as desired without regard to restrictions on the distance between the nozzles of the print head and a recording medium. Further, the present ink jet print head **90** is advantageous over the print head as shown in FIGS. **4** and **5**, since the CTE adjusting plate **92** does not place any restrictions on the design of the wiring on the surface of the closure plate **66** of the ink pump member **44**.

The ink jet print head **90** constructed as described above may be modified such that the CTE adjusting plate **92** and the connecting plate **68** of the ink pump member **44** are formed into an integral single member. Referring to FIG. **9** showing such modification by way of example, an ink jet print head **98** has a CTE adjusting plate **92** interposed between the orifice plate **50** of the ink nozzle member **42** and the spacer plate **70** of the ink pump member **44**. The CTE adjusting plate **92** is bonded to the orifice and spacer plates **50**, **70**, and is thus formed as an integral part of the print head **98**. In this embodiment, the connecting plate **68** is incorporated into the CTE adjusting plate **92**.

To produce the ink jet print head **98**, the ink pump member **44** which does not include the connecting plate **68** is first prepared, and then bonded to the CTE adjusting plate **92** and the ink nozzle member **42**, so that the pump member **44** is formed as an integral part of the print head **98**. In the thus obtained ink jet print head **98**, tensile stresses due to the flexural deformation of the ink pump member **44** can be effectively reduced or eliminated, whereby the print head **98** exhibits effectively improved ink jetting capability.

While the present invention has been described in its presently preferred embodiments with a certain degree of particularity, it is to be understood that the invention is not limited to the details of the illustrated embodiments, but may be embodied with various changes, modifications and improvements, which may occur to those skilled in the art, without departing from the scope of the invention as defined in the appended claims.

For instance, the ink nozzle member **42** and the ink pump member **44** may employ various known structures other than those of the illustrated embodiments. While the ink supply channel **62** for supplying the ink material into the ink chambers **46** is formed within the ink nozzle member **42** in the illustrated embodiments, the ink supply channel **62** may be formed within the ink pump member **44**.

Further, the location and number of the nozzles **54** and orifices **58**, and the location and number of the ink chambers **46** may be suitably Selected as needed, depending upon the application of the ink jet print head, for example.

What is claimed is:

1. An ink jet print head comprising:

a metallic nozzle member having a plurality of nozzles through which fine particles of ink are jetted, and a first and a second opposite major surface;

a ceramic ink pump member having a first and a second opposite major surface, said ceramic pump member being superposed on and bonded to said nozzle member, the first opposite major surfaces of the nozzle member and the ceramic ink pump member being bonded together, said ink pump member having a plurality of ink chambers formed behind respective nozzles of said nozzle member, said ink pump member including a plurality of piezoelectric/electrostrictive elements each disposed on a portion of said ink pump member opposite a respective ink chamber, for deforming said portion so as to change a pressure of the respective ink chamber, whereby the ink supplied to the ink chamber is jetted through the corresponding one of said nozzles; and

coefficient of thermal expansion adjusting means for reducing a stress which is applied to said ink pump member due to a difference between a coefficient of thermal expansion of said nozzle member and a coefficient of thermal expansion of said ink pump member, said coefficient of thermal expansion adjusting means comprising an adjusting member superposed on and bonded to at least one of said nozzle member and said ink pump member.

2. An ink jet print head comprising:

a metallic nozzle member having a plurality of nozzles through which fine particles of ink are jetted, and a first and a second opposite major surface;

a ceramic ink pump member having a first and a second opposite major surface, said ceramic pump member being superposed on and bonded to said nozzle member, the first opposite major surfaces of the nozzle member and a ceramic ink pump member being bonded together, said ink pump member having a plurality of ink chambers formed behind respective nozzles of said nozzle member, said ink pump member including a plurality of piezoelectric/electrostrictive elements each disposed on a portion of said ink pump member opposite a respective ink chamber, for deforming said portion so as to change a pressure of the respective ink chamber, whereby the ink supplied to the ink chamber is jetted through the corresponding one of said nozzles; and

coefficient of thermal expansion adjusting means for reducing a stress which is applied to said ink pump member due to a difference between a coefficient of thermal expansion of said nozzle member and a coefficient of thermal expansion of said ink pump member, said coefficient of thermal expansion adjusting means comprising an adjusting member that is superposed on and bonded to the second opposite major surface of said nozzle member which is remote from said ink pump member, the coefficient of thermal expansion of said adjusting member being smaller than the coefficient of thermal expansion of said nozzle member.

3. An ink jet print head as defined in claim 2, wherein the coefficient of thermal expansion of said adjusting member is smaller than the coefficient of thermal expansion of said ink pump member.

4. An ink jet print head as defined in claim 2, wherein said adjusting member has a thickness of not larger than 0.1 mm.

5. An ink jet print head comprising:

a metallic nozzle member having a plurality of nozzles through which fine particles of ink are jetted, and a first and a second opposite major surface;

a ceramic ink pump member having a first and a second opposite major surface, said ceramic pump member being superposed on and bonded to said nozzle member, the first opposite major surfaces of the nozzle member and the ceramic ink pump member being bonded together, said ink pump member having a plurality of ink chambers formed behind respective nozzles of said nozzle member, said ink pump member including a plurality of piezoelectric/electrostrictive elements each disposed on and directly bonded to a portion of said ink pump member opposite a respective ink chamber, for deforming said portion so as to change a pressure of the respective ink chamber, whereby the ink supplied to the ink chamber is jetted through the corresponding one of said nozzles; and

coefficient of thermal expansion adjusting means for reducing a stress which is applied to said ink pump member due to a difference between a coefficient of thermal expansion of said nozzle member and a coefficient of thermal expansion of said ink pump member, said coefficient of thermal expansion adjusting means comprising an adjusting member that is superposed on and bonded to the second opposite major surface of said ink pump member which is remote from said nozzle member.

6. An ink jet print head as defined in claim 5, wherein the coefficient of thermal expansion of said adjusting member is larger than the coefficient of thermal expansion of said ink pump member.

7. An ink jet print head as defined in claim 6, wherein the coefficient of thermal expansion of said adjusting member is equivalent to the coefficient of thermal expansion of said nozzle member.

8. An ink jet print head as defined in claim 5, wherein the coefficient of thermal expansion of said adjusting member is smaller than the coefficient of thermal expansion of said ink pump member.

9. An ink jet print head as defined in claim 5, wherein said adjusting member includes a pair of leg portions which are bonded to said second opposite major surface of said ink pump member, such that the adjusting member passes over said piezoelectric/electrostrictive element.

10. An ink jet print head as defined in claim 1, wherein said adjusting member is interposed between and bonded to said nozzle member and said ink pump member, the coefficient of thermal expansion of said CTE adjusting member being smaller than the coefficient of thermal expansion of said nozzle member.

11. An ink jet print head as defined in claim 10, wherein the coefficient of thermal expansion of said adjusting member is equivalent to the coefficient of thermal expansion of said ink pump member.

12. An ink jet print head as defined in claim 1, wherein said nozzle member consists of a nozzle plate having said plurality of nozzles, a channel plate having a window formed therethrough, and an orifice plate having a plurality of orifices formed therethrough, said ink pump member being superposed on said orifice plate, said window of said channel plate being closed by and between said nozzle plate and orifice plate to provide an ink supply channel through which the ink is fed to said ink chambers of said ink pump member, said orifices communicating with said ink supply channel and said ink chambers, for guiding the ink from the ink supply channel to the respective ink chambers.

13. An ink jet print head as defined in claim 12, wherein said channel plate of said nozzle member has a plurality of through-holes formed therethrough, for permitting discharge of the ink from said ink chambers toward said nozzles, and a multiplicity of holes formed therethrough over an entirety of the area of a surface thereof except said window and said plurality of through-holes.

14. An ink jet print head as defined in claim 1, wherein said ink pump member comprises a closure plate, a spacer plate and a connecting plate which are laminated on each other such that said spacer plate is interposed between said closure plate and said connecting plate, said spacer plate having a pluraltiy of windows that are closed by and between said closure plate and said connecting member to provide said plurality of ink chambers.

15. An ink jet print head as defined in claim 14, wherein said adjusting member consists of said connecting plate of said ink pump member.

16. An ink jet print head as defined in claim 14, wherein said piezoelectric/electrostrictive elements are formed on said closure plate of said ink pump member, each of said piezoelectric/electrostrictive elements consisting of an upper electrode, a lower electrode, and a piezoelectric/electrostrictive layer interposed between said upper and lower electrodes.

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